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Cables :: "Stomata." | Phone :: 2183

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POULTRY IN THE TROPICS.

THROUGHOUT the Colonial Empire the keeping of poultry is almost universal, especially among small holders. As a rule, the type of poultry kept, however, leaves much to be desired. It is generally entirely mongrel, and consists of miserable undersized birds, the greater majority of which obtain a livelihood by a process of scavenging. Such poultry is usually badly housed and but little cared for. The eggs produced are very small, often soiled and of doubtful freshness when consumed, while the flesh of the carcasses is often very poor. Except for the fact that it is hardy and a good forager, the local village fowl has little to commend it. In many colonies, however, it appears to fulfil the demands of the greater part of the population. This is because the native small holder can produce this class of poultry at negligible cost and, however small his produce is, it is almost all profit, whether he consumes it himself or sells it. On the other hand, there are people in every colony, who are able to pay a special price for large, good quality eggs and table birds but their numbers are limited. This demand cannot be met altogether by the large scale poultry farmer of whom there are still too few in the tropics. It would seem, therefore, that the small producer, with his low overhead charges and feeding costs, ought to share in the trade of better poultry products. There is immense scope for the improvement of native poultry but it is doubtful whether any general or widespread improvement will be attained to, until it has been conclusively demonstrated to the native producer that greater costs of production will be repaid by greater returns.

The amount of knowledge available on poultry keeping in the tropics is relatively restricted. A good deal of the experience gained by the pioneers of this industry in the tropics has unfortunately been lost through not being recorded. It is true that more interest has been taken during recent years in the development of poultry in the Colonial Empire but this has so far been confined to certain colonies only. For instance, particularly good work has been done and valuable data collected in Malaya, Tanganyika, Kenya and Zanzibar but apart from these colonies, poultry has received but scant attention elsewhere. The general lack of attention devoted to poultry by many Colonial agricultural departments is probably due to the fact that it is and has been regarded as a minor

industry. More recently, however, it has been recognised that there may be a considerable future for poultry as a side line to mixed farming where it could form an increasingly important part of the cash earnings of the small farmer. Apart from this, there can be no doubt that poultry and eggs comprise two of the many necessities of life. Their increased consumption from the point of view of health seems desirable and would also do something towards balancing the protein deficient diets which are common in the tropics.

Various problems and difficulties confront the poultry industry in the tropics. Chief among these is the disease problem and although in various quarters this has been regarded as secondary and as resulting from improper housing and feeding, there is no question that disease in many colonies constitutes a very serious obstacle to progressive poultry farming. Periodically, the poultry population is heavily reduced by waves of diseases the precise nature of which is often unknown. Much can be done to reduce the incidence of disease by careful management of each flock and by encouraging the adoption of preventive measures such as the isolation and destruction of suspected or infected birds, and the avoidance of all conditions conducive to ill health. Such measures, alone, however, cannot succeed in eradicating disease entirely. The need for more information regarding poultry diseases and their recognition and control is urgent, and more research into the predisposing conditions and the nature of parasites and organisms responsible should be undertaken, as existing knowledge is certainly not adequate.

Another major problem is that of finding a balanced and cheap ration, compounded, as far as possible, from local products. Some very useful information has been obtained, especially in Malaya and Zanzibar, from investigations on this special question. The principal difficulty has been to find a cheap source of animal protein to balance the carbohydrate cereal foods such as maize, sorghum and rice which are commonly fed to poultry. One obvious source of protein-rich food is fish and in Zanzibar it has been found that chickens fed on shark meat showed almost at once great improvement. There is a need in many colonies to develop some plan of preparing meat and fish meal of a high grade suitable for stock feeding. It is possible also that satisfactory poultry rations may be developed by the introduction of vegetable protein in the form of soya bean meal, copra meal and other similar vegetable protein products. Further experiments on the use of these products will be required, however, before their use can be safely recommended.

The breeding problem is an interesting one but should be approached with care as it bristles with uncertainties. Practically all colonies maintain stocks of pure bred poultry. In many of them some marked improvement in the size and productivity of local poultry has been achieved by the introduction of pure bred cockerels which, in some places, are distributed only where a considerable group of applicants undertake to kill off the native cocks in their areas. The most popular breed is the Rhode Island Red which has been shown to stand up well to the climate and to retain its fertility and productivity for at least two generations. It has yet to be shown whether, from a commercial point of view, pure breds will prove superior to cross breds or *vice versa*. A policy of grading up, well conceived, should lead to fruitful results and possibly to the evolution of one or more new local types. The local poultry population certainly appears to deserve more careful study than it has received hitherto with the object not only of isolating improved types, but also from the aspect of the proportion of local blood which should be maintained in the grades.

We have attempted here to review some of the more important aspects of the poultry industry in our Colonial Empire. It will be realised from this brief survey that there are many problems in connection with this industry which require careful study. Our knowledge of poultry management, breeding and diseases in the tropics is still very limited and it seems highly desirable that more adequate provision for research into these problem should be made. What is wanted also is a few men in each of the larger agricultural departments with special training in poultry keeping, such as could be obtained through short courses of three or four months taken while on leave. In view of the great possibilities offered by an improved poultry industry we would urge that all colonies which are not already doing so pay more attention to this industry than they have done hitherto. The valuable experience which has already been gained as a result of investigations and practical work in certain colonies should be pooled before any programme of research or propaganda is embarked upon.

VECTORS OF ROSETTE IN GROUNDNUT.

Of five insects which live on the plant only one, *Aphis laburni* Theob., was found capable of spreading groundnut rosette in the Belgian Congo. Attempts to inoculate local plants by means of this insect were successful in only one case, namely that of *Centrosema Plumieri*, but all attempts to reinoculate from *C. Plumieri* failed. Losses from this virus, which generally produces a chlorotic stunted effect on the groundnut plant, may amount to 80 to 90 per cent. of the crop. It is found that the creeping varieties are most susceptible and that second season are more susceptible than first season plants. The best control methods are as follows:—sow very thickly and delay hoeing, avoid planting two successive plants of groundnut, destroy any old plants which show new growth and use resistant varieties.—(*Horticultural Abstracts*, Vol. X, No. 3, p. 296.)

THE GEOGRAPHICAL DISTRIBUTION OF INSECT PESTS.

By A. M. Adamson.
Imperial College of Tropical Agriculture.

Introduction.

The spread of insect pests by human commerce, which proceeded without restriction until about 50 years ago, has resulted in losses to mankind of enormous proportions. In some countries the damage inflicted by foreign pests greatly exceeds that caused by native insects. Modern methods of control have at last been applied, but some of the world's worst pests are still increasing their range and the enforcement of preventive regulations results in considerable expense and some restriction of trade. New difficulties arise with increased speed of transport. The problems involved in the geographical distribution of destructive insects have received less attention in the literature of economic entomology than their magnitude warrants, and I have seen no comprehensive discussion of these problems for the world as a whole. In the following pages an attempt is made to discuss some of them along broad lines, though within the limits of a short article.

Within the last 20 or 30 years most governments have enacted extensive legislation to exclude foreign insects and have made at least some attempt to enforce it. Public co-operation is increasing steadily, but there still exists a considerable opposition to the enforcement of regulations, and systems of plant quarantine, in particular, have been subjected to some criticism on strictly scientific grounds. It has been claimed that some quarantines, though at first sight justifiable and effective, are in reality worthless, because the insects against which they are directed, and which they appear to have excluded, may be unable to survive in the country concerned. The general concepts on which whole systems of plant quarantines are based have been regarded as doubtfully sound. It has been objected, also, that the restrictions on commerce may result in greater losses than those which might be caused by the introduction of the foreign pests against which the quarantines are imposed. These criticisms, as applied to plant quarantines in California, were recently examined exhaustively and impartially by a committee of experts in the fields of economics and agriculture as well as of entomology and plant pathology. The committee's report (Smith, Essig and others, 1933) affords a clear answer to these questions. It demonstrates the validity of the general concepts upon which the plant quarantines of California are based, a reasonably high standard of efficiency in their application, a relatively small adverse effect on commerce and industry, and the exclusion of many serious pests and diseases which would almost certainly have become established in California in the absence of regulations against their introduction. In these decisions other countries can find an ample justification for maintaining the most efficient systems of legislation against foreign pests which may be feasible in the case of each particular area.

The Dispersal of Insect Pests.

As regards their tendency to extend their range across the natural barriers within which most insects are confined (that is, by seas, high mountains, deserts, &c.), the insect pests may be divided into the following groups:

(1) *Species ranging widely by natural means.*—Many insects can traverse great distances by flight, including ocean barriers. Outstanding examples are the moth of the cotton leaf worm (*Alabama argillacea*), whose migrations from equatorial South America extend north and south, as far as the northern United States; the corn earworm, which has become almost cosmopolitan, partly by virtue of the great range of flight of the adult moth; the locusts, which may traverse continents in successive migrations of the flying swarms. Small insects of weak flight and even wingless species may be borne for long distances in winds at high altitudes. In these and other ways many insect pests have been widely dispersed by natural means. As the problem is one beyond man's control it need not be discussed further here, but it is important to stress the fact that relatively narrow natural barriers may be effective in restricting the spread of many insect pests, at least over long periods. Regulations may be based on the assumption that human traffic is the chief means by which insect pests are likely to cross natural barriers, even though very narrow.

(2) *Insects unavoidably dispersed by man.*—Many insects find it so easy to accompany man in ships and other vehicles of trade that the only means of preventing their spread throughout the world would have been the suppression of almost all commerce. Examples of such pests are the common insect parasites of man, weevils and caterpillars infesting cereal grains, clothes moths, houseflies, cockroaches, many ants. These insects are inevitably world-wide and the problem of their dispersal belongs to the distant past.

(3) *Insects whose dispersal by man may be controlled.*—In this group lies our chief concern as regards preventive measures. It includes innumerable pests which have been more or less extensively dispersed by human agencies, and which may be distributed further in the future, but which might have been, or may in the future be, excluded at least to some degree.

(4) *Insects apparently unlikely to extend their range.*—Certain insects have remained restricted to small areas despite apparent facilities to invade other regions, which appear to offer suitable

habitats for them. Thus one of the sugar-cane froghoppers, *Tomaspis saccharina*, is confined to the islands of Trinidad and Grenada, in spite of unrestricted traffic in the past with neighbouring islands where the physical environment might be expected to be as favourable, and where natural enemies in the form of other insects are probably less numerous. A sugar-cane root grub, *Lachnosterna smithi*, of Barbados was introduced long ago to Mauritius, but has never established itself in other West Indian islands. It might be argued that quarantines to prevent the spread of these two pests in the West Indies are therefore unnecessary. Unfortunately there is no sure method of deciding the question, except by the impracticable experiment of introducing the insects, and it is necessary to regard them as a potential danger.

Among the innumerable ways in which insects may be transported by human commerce, the following principal means may be distinguished:

(1) Insects may travel as stowaways, not attached to any particular objects. Houseflies, cockroaches, and ants may be found on any ship and almost all insect pests may conceivably be transported by this means. In most cases preventive measures are impracticable and the pests most likely to be carried as chance stowaways are already widely distributed. In the case of airplanes, however, the dangers are great, and effective measures may be applied, as discussed below.

(2) Plants or parts of plants for propagation obviously afford the most favourable medium for the introduction and establishment of crop pests, especially scale-insects permanently attached to the surface of plants and insects which bore into stems and seeds. Probably a majority of the widely distributed pests of growing plants owe their dispersal to the free exchange of planting materials in the past. Fortunately the importation of this class of material is more easily controlled, without hindrance to commerce, than other types of article.

(3) All crop products that are not subjected to treatment detrimental to insects are likely to harbour pests to some extent. Most of them are stored products pests, which are already world-wide. The most dangerous of important commodities are fresh fruits, which are liable to infestation by scale-insects and boring insects, especially fruit-flies. Embargoes against importation of fresh fruits are therefore imposed more frequently than in the case of other crop products. Fresh vegetables offer similar dangers.

(4) In many cases agricultural produce may harbour pests because of contamination by such materials as soil, trash and other refuse. The pink bollworm was probably introduced to Egypt in cotton seeds in imperfectly ginned lint. Foliage attached to citrus fruits, carelessly packed, might carry eggs of the citrus root weevils (*Diaprepes*). Many subterranean pests may be transported in soil contaminating potatoes and other ground provisions. It therefore happens in many cases that an embargo is imposed on a crop because of the materials contaminating it, whereas a high grade product subjected to careful selection and cleaning might be freely admitted.

(5) Most of the insect parasites of man and domestic animals travel freely on their hosts. The majority of them have already been widely dispersed.

History of Legislation against Foreign Insects.

Attempts by governments to restrict the spread of insects appear to have begun about 1870. According to the information available, Sasscer (1940) writes that " the first regulation or decree directed against a foreign insect was that of Germany, in 1873 ", with reference to the grape root aphid. In 1876 an ordinance was enacted in Malta, " To prevent the introduction of diseases affecting agricultural produce ". In 1883 plant quarantine legislation was adopted by the State of California. Other governments followed these leads in more or less rapid succession. In Trinidad, for example, a " Plant Protection Ordinance " was passed in 1894. Strangely enough, the government of the United States was among the last in the more advanced countries to take action, and the Federal Plant Quarantine Act, for the United States as a whole, was not passed until 1912. Some of the worst insect pests introduced early in the century, might have been excluded if action had been taken a few years earlier. But having suffered so much from introduced pests, the United States finally took the lead in energetic enforcement of regulations against further invasions.

Though most governments adopted some kinds of regulations against foreign insects during the early years of this century, it was probably not until about 1920 that any country had a comprehensive and adequate system of legislation which was enforced with energy and efficiency. Thus in California, which led in this field from the beginning, the annual quarantine budget in 1916 was only $25,000; a border inspection service, against pests from other parts of North America, was not instituted until 1921. In many countries the energetic enforcement of adequate legislation was begun only within the last ten years.

Three periods may thus be recognised in the history of man's efforts to prevent invasions of foreign insects: 1870 to 1900, the first attempts at legislative action by a few governments; 1900 to 1920, the passing of legislation in most countries and progress in attempts to enforce it; 1920 to 1940, the adoption of reasonably efficient systems of control in most of the advanced countries. In many parts of the world there is probably great room for improvement and adequate international co-operation has yet to be attained.

The Nature and Enforcement of Legislation.

The ideal objective for any area enclosed in effective natural barriers is the exclusion of all foreign animals and plants, except those of which the importation is desired. On this assumption any procedure likely to result in the introduction of unrequired foreign organisms, whether known with certainty to the pests or not, should be prohibited unless there are adequate reasons for permitting it—that is, unless the procedure is necessary for some particular purpose or if its prohibition is too difficult to enforce. This ideal may seem fantastically impracticable, but in the case of many areas it is, or should be, not so far removed from actual practice as might appear at first sight, owing to the extensive control which governments exercise over the entry of articles of all kinds.

In all or almost all countries a general law gives the government authorities powers to restrict the importation of all kinds of articles, especially plants and crop products, and to control the movements of vehicles of commerce. The extent of the restrictions vary greatly, but the following are widely adopted procedures.

All planting materials, except seeds of flowers and vegetables in certain cases, must usually be declared and presented for inspection, and permits must be obtained in advance for most growing plants. The principal crops of particular countries are usually protected by an absolute prohibition against imported planting materials (other than edible grains, pulses, &c.) unless the importation is made by the proper government authorities. In special cases plants closely related to crop species may be excluded; for example all live parts of members of the Gramineae or grass family, except the edible grains, may be prohibited to exclude pests and diseases that might attack sugar cane. The importation of soil, with or without plants, is prohibited because it may harbour many insect pests and micro-organisms of disease.

The importation of major crop products is restricted to an extent which is probably less than one might imagine to be necessary. Certain sweeping embargoes may be necessary in some cases, for example against almost all fresh fruits from Hawaii to the United States, to prevent the introduction of the Mediterranean fruit fly. Most embargoes are naturally imposed in the case of products which are grown locally in adequate quantity. In some cases importations may be permitted if subject to inspection at the point of shipment, but this is not widely adopted as inspection of large consignments is unreliable for the detection of most insect pests. Treatment to eliminate insect infestations, for example by fumigation, is likewise not generally practised in the case of large commercial shipments as a means of satisfying quarantine regulations.

Certain countries prohibit the importation of any live insects, except by government authorities. Though the number of such importations is never likely to be large, this is a wise measure and should be more generally applied.

The enforcement of regulations prohibiting the importation of many kinds of articles in cargoes, passengers' baggage and mails, presents problems of great magnitude. Fortunately a partial solution of most of them is provided by customs services. Inspections in most cases are entrusted to customs officials who detain prohibited articles, and inform quarantine officers when necessary. Customs regulations, requiring the declaration of prohibited articles such as plants, afford an easy means of reducing importations made in ignorance of the law. If free trade should ever eliminate the necessity for the customs examinations now enforced by most countries, the quarantine authorities would have to extend their activities very greatly.

Special inspections by plant quarantine officials are required in relatively few cases. The border inspection in California, against pests from other parts of the United States and from Mexico, necessitates the examination of all road vehicles. The inspection of ships from Hawaii, to prevent the introduction of the Mediterranean fruit-fly to California, is conducted by quarantine officials before any landing is permitted. Vessels liable to infestation by the cotton boll weevil must be cleared by an inspector on arrival at certain West Indian islands. The special requirements for air transport are discussed below.

In general, it seems safe to conclude that the enforcement of measures against foreign insects has a relatively small adverse effect on commerce and on the liberties of the people—certainly a very small effect in comparison with the losses that might be incurred if pests were allowed free entry. Embargoes are mostly imposed on products grown locally in sufficient quantity. No serious privations are incurred and interference with the movement of ships and other means of transport, and with the handling of cargoes and baggage, is relatively small.

Plant Quarantine Stations.

The safe introduction of planting material of the major crops of any area is effected by passage through a plant quarantine station. There the material, imported in minimum quantity, is subjected to careful examination by specialists and if necessary it is grown for one or more generations in isolation in quarantine greenhouses. The elimination of insects is effected fairly easily, especially as a long and rigorous quarantine may be required to exclude diseases of which the symptoms may be masked for considerable periods.

A typical quarantine greenhouse is of glass and fine wire gauze, and surrounded by a moat to exclude insects such as ants. Soil is sterilised before and after use, and all articles liable to infection by diseases or pests, except the planting materials, are sterilised before removal from the house. The exclusion of all small insects is scarcely practicable in the case of most greenhouses as they may pass through the finest mesh, but infestations can be prevented by the use of insecticides and planting materials free from pests

can be prepared for release. The ideal quarantine house for plants would be completely sealed and air-conditioned, and the plants grown by water-culture. Such perfection is scarcely necessary. So far as I am aware, no foreign pest or disease has been introduced with plants grown at a recognised quarantine station.

The establishment of quarantine stations, in most countries, is comparatively recent. Among the most important are those at the Royal Botanic Gardens at Kew, serving the British Empire, and of the U. S. Department of Agriculture at Washington. Among recently established stations are those at Amani, Tanganyika, for the British Colonies in East Africa, and at Trinidad for the British West Indian area. There is probably room for many more stations than exist at present.

Air Transport.

Fortunately transport by airplanes was not achieved until restrictions against foreign insects had become fairly effective. Otherwise many pests would be much more widely distributed than they now are. The introduction of one of the very worst insect pests, however, may have been due to air transport. In 1930 an African malarial mosquito, *Anopheles gambiae*, was discovered in Natal, Brazil, and being an exceptionally effective vector of malarial parasites and a difficult species to control, it has caused very serious epidemics of the disease in eastern Brazil. The means of its introduction are not known with certainty but it is at least possible that it came as a stowaway by air. Up to 1930 aircraft had crossed the South Atlantic on eight occasions, mostly from Dakar to Natal (Whitfield, 1940).

The nature of the articles carried by planes, and their relatively small amount, make the detection of prohibited articles easier than in the case of other means of transport. The greatest danger, under present conditions at least, appears to lie in insects boarding planes on the ground, not attached to any particular object such as plants, and being carried swiftly across barriers which would be effective against stowaways in slower means of transport. The number and variety of insects carried in this way are very large. Whitfield (1940) compiled a list of 227 species of insects found in commercial aircraft throughout the world. They represent all the main orders of insects and include many pests of great medical and agricultural importance. In addition to the danger of importing foreign pests is the even graver risk of introducing diseases in infected insect vectors such as the mosquito of yellow fever.

Some progress has already been made in eliminating these risks. Partial fumigation of planes in flight, and thorough fumigation after passengers land, have become routine practices along certain air routes. Planes crossing the Pacific from the Orient to San Francisco are subjected to thorough examination and treatment by officers of the U.S. government at Midway Island, the last stop before Honolulu. Some countries have already adopted especially stringent regulations against the importation of plants by air. But efficient systems of control along many of the great air routes of the world have not yet been adopted. As Whitfield (1940) points out, an entirely satisfactory insecticidal treatment for planes in flight has not yet been devised. It should be a permanent part of the equipment of the plane, operated with a minimum of effort, and the insecticide should be highly toxic to insects and innocuous to passengers and materials. A satisfactory technique should be achieved before long.

Anopheles gambiae is the only insect pest suspected of having been introduced by air transport, so far as I know. If the proper action is taken soon on all important air lines crossing great natural barriers, it may be long before such a disaster is repeated.

Efficacy of Methods of excluding Foreign Insects.

The extent to which the dispersal of insect pests has been restricted by modern methods of control cannot be estimated precisely. The insects most liable to be dispersed had been distributed widely before extensive measures against them were in operation, and experimental investigations on the efficacy of quarantines are obviously impracticable. The list of recent introductions given below shows that the restrictions are far from being entirely effective but it is reasonable to conclude that the number of introductions during the last 20 years would have been much greater if no control had been attempted. There is much circumstantial evidence in favour of this opinion. An excellent example, cited by Smith, Essig and others (1933), is that of the eucalyptus in California, where it was introduced by means of seeds only and was not accompanied by any of its numerous pests in Australia. Several of these pests have become established in South Africa and New Zealand, probably introduced on nursery stock brought to these countries. Innumerable foreign pests are intercepted by inspectors—234,858 interceptions of insects were made at U.S. ports of entry in 1935 to 1939 (Sasscer, 1940), many of which were of species not established in North America and presumably potential pests there. Obviously a large number of insects escaped detection at these ports but the restrictions are worth while if they sufficiently reduce the numbers of any particular pest and the frequency with which it is introduced. The establishment of an insect in a new country may be attended with great difficulty and even a partial exclusion of immigrants may render it impossible.

The introduction of new pests in spite of measures against them might be used as an argument both for and against quarantine methods. The following are outstanding examples of the introduction of important pests during the last

20 years (the dates are those of discovery or first published record): the Mediterranean fruit fly in the United States in 1929 (in Florida, but subsequently eradicated), Venezuela in 1931, and India in 1938; the Colorado potato beetle, which has spread extensively in north-western Europe since its introduction with potatoes sent to U.S. troops in France in 1918; *Anopheles gambiae* in Brazil in 1930, possibly by airplane from West Africa as mentioned above; the cotton boll weevil in Haiti, 1932; the coffee berry borer in Ceylon, 1935; the white fringed beetle in the southern U.S., 1936; the rice-borer (*Chilo simplex*) in Hawaii, 1928-29, in rice straw from the Orient; the satin moth in the eastern U.S., 1920; two destructive termites from the Orient, one in the West Indies, 1938-39 (*Coptotermes havilandi* in Jamaica and Barbados) and one (*Coptotermes formosanus*) in South Africa, 1927.

A new and hopeful aspect in the problem of foreign pests is introduced by recent successes in eradication of insects from invaded territories. The outstanding example is that of the Mediterranean fruit fly in Florida, where it was completely exterminated in an area of 15,000 square miles of fruit-growing lands less than 18 months after its discovery in 1929, by one of the greatest single achievements in the history of economic entomology. Other examples are the eradication of the pink bollworm from several states in the U.S. cotton belt (though it persists in others); of the date palm scale from the south-western U.S.; of the gypsy moth from 400 square miles of infested lands in New Jersey; of Anopheline mosquitoes from Barbados; of the Colorado potato beetle in southern England before it had gained a firm hold. With improvements in methods of destroying insects and experience in detecting infestations and organising campaigns against them, the eradication of introduced pests should become more and more practicable.

There is therefore reason to hope that the distribution of insect pests will not continue slowly but surely until all pests capable of being transported by commerce have become establishhe in all regions favourable to them. During the last 50 years the progress made in methods of controlling insect pests has been offset to a considerable extent by the introduction of new pests from abroad. This tendency is not likely to be continued in the future.

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THE PRODUCTION OF FIELD PLANTS OF THE CLOVE TREE.

In a paper on this subject, published in the *E. Afric. Agric. Jr.*, Vol. V, 1940, L. G. T. Wigg describes the nursery methods used in the production of clove plants from selected seed for sale to growers in Zanzibar. The method produces a greatly improved plant in comparison with the self-sown seedlings which are commonly employed. The fruit is collected from under the selected tree at regular intervals, the ground being swept after each collection. The fruits are soaked for two or three days in water to remove the outer flesh and assist germination. The single seed (rarely two) then disclosed consists of two large green cotyledons and a well-developed radicle. Desirable characters for selection are described, the chief of these being that the cotyledons should be of a fresh olive green colour and not reddish, and the radicle should not be blackened. The weight of good seed is about 400 to the pound. Rigorous selection rejects about 48 per cent. and should ensure a germination of about 96 per cent. from the remainder. Seed beds are prepared some time in advance and the fine tilth maintained by a thick litter of old leaves. Removable overhead shade is provided 7 feet above the bed. When sowing the litter is raked off and a bed marked with a band drill roller in lines 8 inches apart. Over these lines a batten provided with pegs 4 inches apart is pressed and in the holes so formed the seed is placed radicle downwards, half the seed extruding. The litter is then replaced without further covering with soil. Seed inserted in other than the correct position produces contorted plants. As the seeds germinate they are freed by the drawing back of the litter, which, however, must remain on the beds. The first pair of leaves should have expanded in a month from sowing. Transplanting to nursery rows is done when the seedlings are 2-3 months old. The ball of earth must be left on the roots but long main roots may be reduced. A month or two before the plants leave the nursery for the field they are again lifted, the ball of soil wrapped in banana leaves (failing a more satisfactory material) and the plants stood under shade close together for mutual support. This results in the production of many turgid white roots. The need for the ball of soil creates a serious problem for the nursery for, as the authors point out, a nursery distributing 40-50,000 plants a year would at the same time distribute about 200 tons of its best soil. Experiments with bare root planting on a field scale have been unsuccessful, though bare root plants pretreated as above have been established in sterile sand for pot culture experiments without any sign of shock.—(*Imp. Bur. of Hort. & Plan. Crops, Hort. Abstracts*, Vol. X, No. 2, Abs. 695, pp. 167-68, 1940.)

THE COLLEGE PERMANENT MANURIAL EXPERIMENT

By R. Cecil Wood,
(*Lately Professor of Agriculture, Imperial College of Tropical Agriculture.*)
and F. Hardy.
(*Professor of Chemistry, Imperial College of Tropical Agriculture.*)

(I) Introduction.

A manurial experiment was inaugurated in January, 1931, on Field 8, with the primary object of ascertaining the chief nutrient deficiencies and responses to manuring of the College Farm soil. The method was to treat a series of plots identically for a period of years with the same manures, and to crop them intensively throughout. No plot-replication was attempted; the experiment was designed simply as a qualitative demonstration; land was not available for the laying down of Latin squares or randomised blocks necessary for statistical assessment of yield data. A similar experiment had previously been initiated by one of us (R.C.W.) at the Central Farm, Coimbatore, South India; the results for the first 13 years of that experiment have been discussed by R. V. Norris.*

* Note on the Permanent Manurial Plots, Coimbatore, R. V. Norris. *Mem. Dept. Agric., India*, Chem. Series, VI, 1921-23, pp. 245-254.

(II) Crop Responses.

The layout and treatments are indicated in Diagram I. There are 16 plots, each 1/20 acre, arranged in two rows. Arrangements are provided for irrigation when needed. The manures employed were:—

(i) Nitrogen (N): Sulphate of ammonia (20 per cent.), 110 lb. ac.

(ii) Phosphate (P): Superphosphate (18 per cent.), 176 lb. ac.

(iii) Potash (K): Sulphate of potash (52 per cent.), 55 lb. ac.

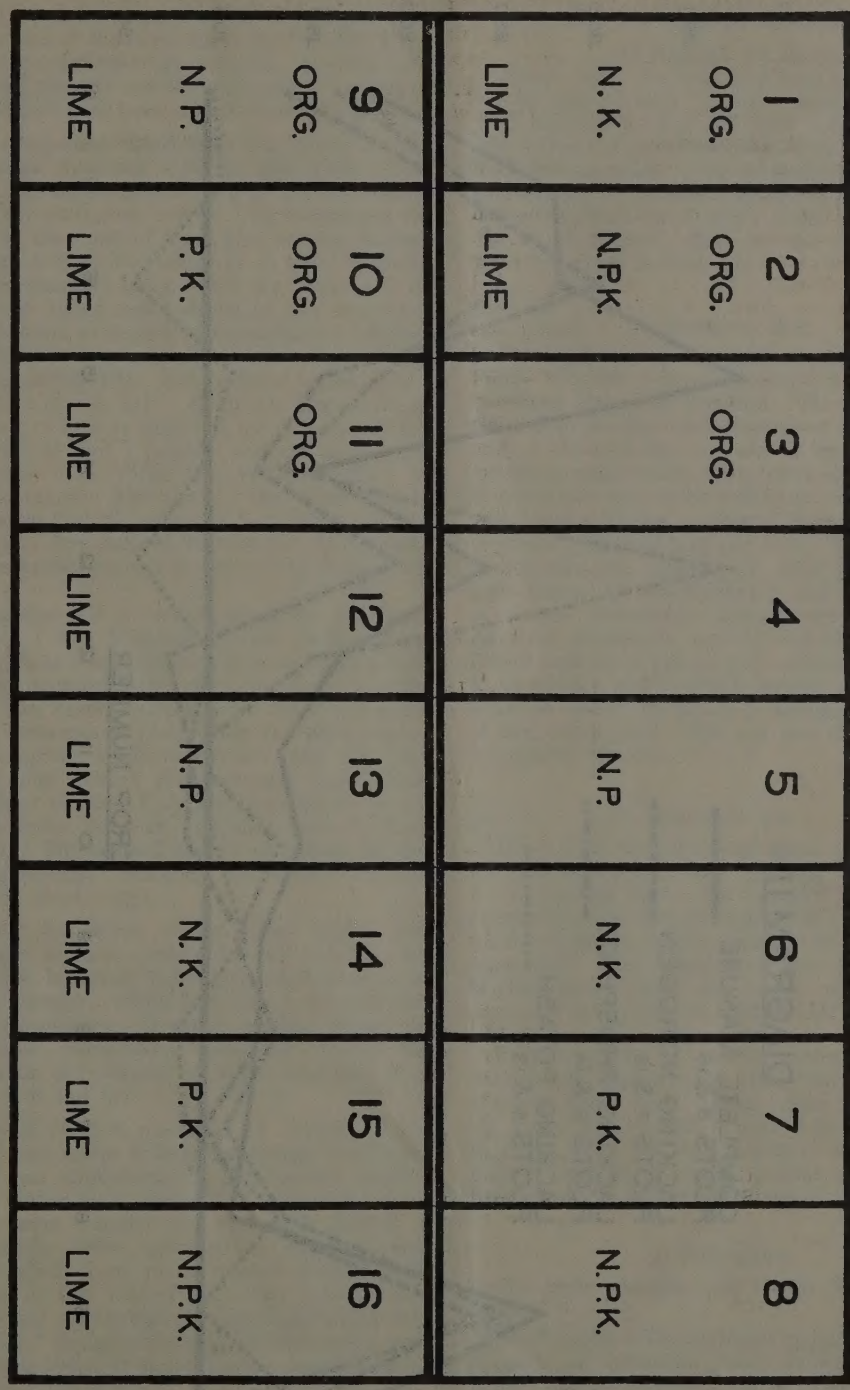
(iv) Organic (Org): Pen Manure and compost, 10 tons ac., later (1933) reduced to 5 tons ac.

Ten of the plots were limed with ground limestone, 10 tons per acre. The manures were applied to every crop, but the lime was applied only once at the beginning of the experiment. The dressings of organic manure were halved in 1933 and after.

Table I.—Comparative Yield Data.

No. of Crop	Crop Plant		1 Control (No manure).	2 Lacking K (NP)	3 Lacking P (NK)	4 Lacking N (PK)	5 Complete (NPK)	6 No Lime	7 Lime (L)	8 Lime Organic (L: Org)	9 Organic (Org)	10 Organic Lime (L: Org)
	Plots		4 12	5 13	6 14	7 15	8 18	†	‡	§	3	11
1	Hill Rice		—	—	—	—	—	—	—	—	—	—
2	Kidney Bean		—	—	—	—	—	—	—	—	—	—
3	Sunnhemp		—	—	—	—	—	—	—	—	—	—
4	Maize	(G)	100	154	106	154	183	100	96	107	100	143
		(S)	100	98	144	136	126	100	109	122	100	76
5	Cotton		100	99	261	246	282	100	92	221	100	90
6	Millet	(G)	100	140	144	127	115	100	100	119	100	93
7	Maize	(G)	100	91	111	102	123	100	130	154	100	94
		(S)	100	98	117	105	114	100	131	161	100	82
8	Kidney Bean	(G)	100	84	139	133	129	100	120	325	100	100
		(S)	100	75	112	123	89	100	117	325	100	66
9	Broom Corn	(G)	100	123	115	120	130	100	141	180	100	120
		(S)	100	114	78	93	94	100	125	167	100	84
10	Maize	(G)	100	106	140	89	151	100	103	162	100	80
		(S)	100	90	130	96	149	100	101	181	100	92
11	Kidney Bean	(G)	100	90	91	91	139	100	167	278	100	134
		(S)	100	101	109	100	139	100	196	213	100	103
12	Tobacco		100	101	157	79	170	100	112	477	100	78
13	Sword Bean	(G)	100	63	380	203	250	100	64	236	100	60
		(S)	100	81	105	44	54	100	79	157	100	77
14	Maize	(G)	100	96	139	125	153	100	107	146	100	99
		(S)	100	105	165	155	197	100	83	112	100	78
15	Tobacco		100	111	193	161	384	100	78	228	100	67
16	Sword Bean	(G)	100	60	257	307	286	100	120	304	100	127
17	Cotton		100	104	242	229	282	100	126	204	100	111
18	Soybean	(G)	100	103	166	138	186	100	157	352	100	190
		(S)	100	84	163	107	184	100	124	298	100	131
	Mean (Grain		100	101	176	159	185	100	117	214	100	111
	(Straw)		100	96	134	109	155	100	114	222	100	85

G=grain. S=straw. † Column 6: No lime, Plots 4, 5, 6, 7, 8.
‡ Column 7: Lime, Plots 12, 13, 14, 15, 16. § Column 8: Lime and Organic Manure, Plots 1, 2, 9, 10, 11.



PERMANENT MANURIAL EXPERIMENT : PLOT LAY — OUT

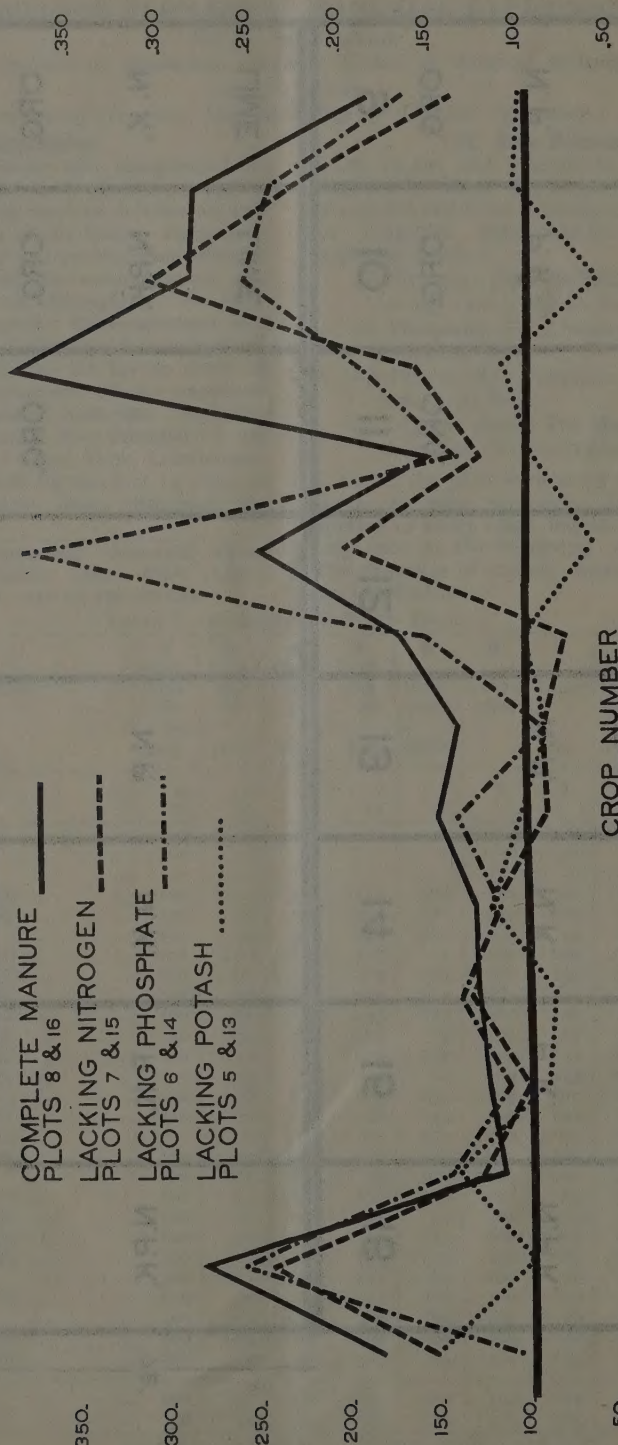


DIAGRAM II
COMPLETE MANURE
PLOTS 8 & 16
LACKING NITROGEN
PLOTS 7 & 15
LACKING PHOSPHATE
PLOTS 6 & 14
LACKING POTASH
PLOTS 5 & 13
CROP NUMBER
350.
300.
250.
200.
150.
100
50.
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18

The plots were cropped 18 times during the first seven years of the experiment (to October, 1937), an average of three crops per year. The list shows the crops planted and the comparative yields of produce obtained from 15 of them (Table I).

For comparing the different artificial manure treatments (Columns 1 to 5), the yield of the control (no manure) plot, No. 4, has been taken as 100 for each crop reaped. In comparing the effects of lime and of lime *plus* organic manure (Columns 6 to 8), the yields of all plots receiving artificial manures but no lime (*i.e.* Plots 4 to 8), have been added and reduced to 100 as a basis of comparison with plots receiving lime in addition to artificial manures (*i.e.* Plots 12 to 16), and with plots receiving lime and organic manure (*i.e.* Plots 1, 2, 9, 10, 11). A further assessment of the effect of lime is afforded by reducing to 100 the yields of Plot 3 (organic manure alone), and comparing with them the yields of Plot 11 (organic manure *plus* lime). The yield data in many cases include values for both grain (G) and straw (S). The data in Table I for the artificial manuring are expressed graphically in Diagram II.

Discussion.—It is evident from the yield data in Table I and Diagram II that plots lacking potash (Plots 5 and 13) among those treated with artificial manures have given the lowest yields, which have hardly differed from the yields given by the unmanured plot, while the plot treated with complete artificial manure and the plot treated with potash *plus* nitrogen have given the highest yields. Thus potash seems to be the most deficient nutrient, and phosphate the least deficient. The natural supply of potash in the soil apparently became inadequate at the 13th crop (Sept. 1935).

Liming has given disappointing results and seems not to have conferred much benefit. All the crops, however, have responded greatly to organic manure, which has about doubled the yields throughout. Organic manure seems to have been particularly beneficial during the abnormally dry seasons of 1933, 1934 and 1935 (Crops 5, 8 and 12).

Samples of seed produced by certain of the crops grown under different manurial treatments showed no difference in germinating ability, though cotton seeds reaped from the plot lacking potash were smaller in size and showed a significantly lower germination capacity than seeds reaped from plots treated with potash. Samples of lint reaped from two cotton crops (Nos. 5 and 17) showed no significant differences in quality,* though the yields of seed cotton were more than twice as great for the potash-treated plots as for the others.

* *See* R. C. Wood, Potash Starvation and the Cotton Plant, *Empire Cotton Growing Review*, (1) XI, 1934, pp. 25-29; (2) XV, 1938, pp. 30-34. The samples of lint were tested at the Shirley Institute, through the courtesy of the Empire Cotton Growing Corporation.

(III) Soil Nutrient Relationships.

(1) History of Plots.

Before 1925, the land had been abandoned for a long time to bush; it was cleared and planted with bananas in 1925, and with tobacco in 1929. The soil of the plots was sampled in January 1931, and the samples were examined by routine methods by the laboratory staff of the Chemistry Department of the College, under the charge of Mr. G. Rodrigues. Data for the surface 6 ins. layer are given in Table II.

(2) Original Soil.

The soil-type is a deep detrital phase of Maracas Sand, derived from quartzose schists of the Northern Range of Trinidad. The plot samples showed an average sand content of 44.5 per cent. and a silt-and-clay content of 55.5 per cent. (of which most is silt), with Index of Texture, 16. The reaction was acidic (pH 6.2); organic matter and total nitrogen contents were medium-low (1.76 per cent. and 0.13 per cent.), with very low carbon-nitrogen ratio (7.7), implying either a high degree of decomposition and humification, or profile truncation through surface erosion. Available phosphate content was on the borderline of deficiency (38 p.p.m.; adequacy accepted at 35 p.p.m.), and available potash was definitely deficient (only 58 p.p.m.; adequacy accepted at, say, 125 p.p.m.). The soil was quite uniform throughout the area.

(3) Manured Soil.

The soil of the plots was again sampled after the experiment had been running for six years, *i.e.*, in January 1937. The results of its laboratory examination are also given in Table II below those for the original sampling, each plot being considered separately. The laboratory data for the soils of the plots after six years' manuring are expressed graphically in Diagram III.

Inspection of the paired values reveals the nature and approximate magnitudes of the soil changes that have taken place during the six years' period, but it should be remembered that the recorded values merely represent the *residual contents* of organic matter and nutrients present in the soil at the times of sampling.

(4) Discussion.

The main changes and trends have been as follows:—

(*a*) *Reaction.*—The artificial manures containing sulphate of ammonia have increased the soil acidity about four-fold (*i.e.* from pH 6.2 to pH 5.8), but lime has created highly alkaline conditions (pH 8.1). Organic manure (containing basic "ash" components) has neutralised the soil acidity, and cultivation of the control plot has apparently also diminished its acidity. These results are in accordance with expectation.

TABLE II.—COMPARISON OF SOIL BEFORE AND AFTER MANURIAL TREATMENT AND CROPPING.
(*Surface 6-ins. layer.*)

Plot.	Treatment.	Silt+Clay %	Reaction Norm. pH.	Reaction Exch. pH.	Total O.M. %	Total N. %	C/N Ratio	Avail. Nutr. mhos × 10⁻⁶	Rate of Soln.	Av. P_2O_5 p.p.m.	Av. K_2O p.p.m.
4	Control	51	6.1	5.5	1.71	0.13	7.6	72	37	39	40
		46	6.7	5.9	1.46	0.11	7.7	51	35	24	82
5	NP	54	6.2	5.5	1.76	0.13	7.9	84	73	50	50
		48	5.8	5.1	1.61	0.12	7.8	71	45	37	62
6	NK	59	6.2	5.6	1.73	0.13	7.7	92	19	60	57
		51	5.7	4.9	1.66	0.11	8.8	93	41	18	90
7	PK	61	6.1	5.4	1.70	0.14	7.0	78	21	38	49
		56	6.7	5.7	1.76	0.14	7.3	75	49	51	93
8	NPK	61	6.4	5.8	1.64	0.13	7.3	100	36	35	37
		56	6.1	5.2	1.82	0.13	8.1	82	58	40	87
12	Lime	55	6.0	5.5	1.78	0.13	7.9	74	11	28	58
		43	8.1	7.6	1.37	0.11	7.2	240	151	49	67
13	L.NP	58	6.0	5.4	1.73	0.13	7.7	69	11	33	46
		48	8.0	7.5	1.46	0.11	7.7	236	151	111	63
14	L.NK	61	6.0	5.5	1.90	0.14	7.9	74	28	34	75
		53	8.1	7.6	1.47	0.12	7.1	194	158	49	75
15	L.PK	62	6.0	5.3	1.73	0.13	7.7	65	17	24	69
		54	8.2	7.4	1.55	0.11	8.2	234	190	98	84
16	L.NPK	68	5.9	5.2	1.74	0.13	7.8	70	28	27	62
		59	8.1	7.5	1.74	0.11	9.2	265	140	118	98
3	Organic	47	6.2	5.7	1.74	0.13	7.8	105	37	49	73
		47	7.3	6.5	1.74	0.13	7.8	114	60	82	110
11	O.L.	46	6.4	5.9	1.70	0.13	7.6	92	27	49	69
		40	8.0	7.6	2.02	0.13	9.0	280	201	141	141
9	O.L.NP	51	6.6	6.2	2.05	0.14	8.5	126	58	(114)	48
		47	7.7	7.3	2.27	0.14	9.4	262	183	235	148
1	O.L.NK	62	6.2	5.7	1.71	0.13	7.6	93	60	60	62
		45	7.8	7.5	2.27	0.14	9.4	219	177	157	178
10	O.L.PK	47	6.3	5.8	1.64	0.12	7.9	90	37	45	69
		43	7.8	7.5	2.00	0.13	8.9	312	167	231	170
2	O.L.NPK	50	6.2	5.7	1.88	0.13	8.4	96	(150)	50	64
		48	7.5	7.5	2.18	0.14	9.0	213	160	180	148
	Means Before	56	6.2	5.6	1.76	0.13	7.8	85	33	38	58

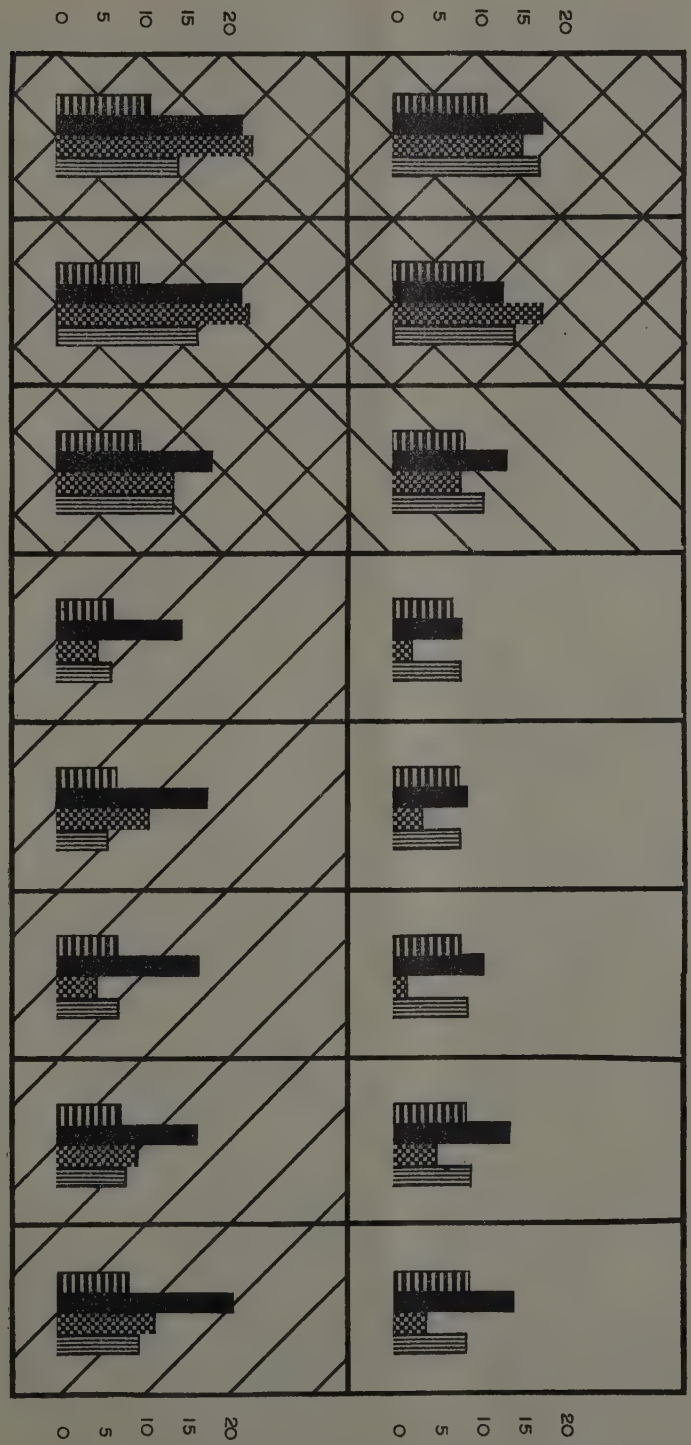


DIAGRAM III
PERMANENT MANURIAL EXPERIMENT
COLLEGE FARM: FIELD 8:
SOIL RESIDUAL NUTRIENTS AFTER 6 YEARS' CONTINUOUS CROPPING
20
15
10
5
0
PLOTS RECEIVING ORGANIC MANURE
PLOTS RECEIVING LIME
ORGANIC MATTER × 5
NITRATE (NO3 × 3/5)
PHOSPHATE (P2O5 ÷ 10)
POTASH (K2O ÷ 10)
in top 6-ins. of soil
(percent.)
(parts per million of dry soil)

(*b*) *Organic Status.*—The soil of the control plot has lost by natural wastage a considerable amount (15 per cent.) of its original organic matter in addition to incorporated crop residues. Certain of the plots treated with artificial manures have also lost some of their organic matter, though the plot which was treated with complete manure seems to have gained a little. Lime has greatly diminished (by about 20 per cent.) the original organic matter content, which is a well-known "wastage" effect. The amounts of organic manure added have been just sufficient to maintain the organic status of the soil, and have made up for natural losses. In most cases, the carbon-nitrogen ratio has been raised, a natural result of the addition to the soil by the crops of organic residues, mainly roots, which have not yet been completely decomposed.

(*c*) *Nitrate Status.*—Special incubation tests (the results of which are not included here) demonstrated that liming had greatly enhanced nitrification, but that sulphate of ammonia had not appreciably increased the reserves of nitrate in the soils not treated with organic manure. Where organic manure had been used, however, the nitrate-supplying ability of the soil had been appreciably increased.

(*d*) *Phosphate Status.*—The control plot soil has lost a large proportion (38 per cent.) of its initial content of available phosphate (Truog's method) as a result of continuous cropping and leaching by rain, but the addition of superphosphate has adequately made up for crop usage and leaching losses. Liming in due course released considerable reserves (75 per cent. increase) of phosphate, which were presumably fixed in the original soil as iron and aluminium phosphates, or as insoluble organo-phosphatic compounds.

Organic manure has greatly increased (by 67 per cent.) the available phosphate reserves of the soil. Evidently the dressings of superphosphate manure have supplied sufficient phosphate, while the dressings of organic manure have more than satisfied the demands made by the crops for phosphate.

(*e*) *Potash Status.*—The control plot soil has apparently gained a considerable amount of available (exchangeable) potash, presumably through the liberation of potash from soil minerals such as potash-mica which is particularly abundant in this soil. Continuous cultivation and crop growth are known to exert this effect. The addition of sulphate of potash alone has greatly increased (by 87 per cent.) the available (exchangeable) potash reserves of the soil, in spite of potash usage by the growing crops, but it has not raised the level of available potash in the soil to the value regarded as denoting adequacy. The addition of lime alone has only released a small proportion of potash (16 per cent. of the total available), but it seems to have diminished the accumulations of potash reserves when potassium sulphate was applied together with lime, though this effect may be the result of a simple base exchange process, whereby calcium in excess has displaced and liberated adsorbed potassium, which has subsequently been lost by leaching or by absorption by plant roots.

Organic manure has greatly increased the available (exchangeable) potash content of the soil (by 51 per cent.), implying that the manure was highly potassic. Thus, plots that had not been treated with organic manure but had received sulphate of potash gave an average value of 88 p.p.m. of available reserve potash, while those that had been treated with both organic manure and sulphate of potash gave a value of 149 p.p.m., which is above the level thought to denote adequacy. The plot that had been treated with organic manure alone showed a reserve of available potash which would be regarded as nearly adequate for the growth of the majority of tropical field crops.

(IV) Nutrient Balance Sheet.

Unfortunately, the plant materials produced by the different crops in this experiment were not analysed chemically, hence a reliable "balance sheet", in which the outgo of nutrients is offset against manurial additions and the soil's natural reserves, cannot be constructed, although the credit side may fairly accurately be stated. An attempt, however, has been made (Table III) to assess the removal of nutrients by each of the various crops by assuming an average chemical composition for that crop as recorded in the chart forming the frontispiece of the book "Potash Deficiency Symptoms", compiled by Dr. O. Eckstein *et al.*, and published in 1937 (Verslag für Ackerbau, M. B. H., Berlin).

The first column of Table III gives the total amounts (lb. wt. per plot) of nitrogen, phosphate and potash actually added as manures to the various plots over the whole period of the experiment. In the case of the organic manure, it has been assumed that all of the total nitrogen has been utilised, on the grounds that chemical analysis showed no significant gain in residual soil nitrogen.*

* It is usually assumed nowadays, as a result of the Rothamsted and other researches, that only a fraction of the total nitrogen of farm-yard manure and composts is actually available for crop growth. The figure is fixed at one-third for farmyard manure and one-half for composts in manurial experiments in which organic nitrogenous manures are compared with sulphate of ammonia. In the case of the Permanent Manurial Experiment, residual nitrogen from one application of organic manure may slowly have become available during subsequent time, so that, in the long run, the nitrogen content was fully mobilised and either utilised at once by the growing crops or lost by leaching. Reference to Table II reveals the fact that the soil of plots treated with organic manure and potash and lime seems to have fixed some nitrogen (0.01 per cent., or about 10 lb. per plot), suggesting that only about 1/6 of the total nitrogen added in the organic manure may have been immobilised and rendered not immediately available.

TABLE III.—NUTRIENT BALANCE SHEET.

(*Surface 6-ins layer of soil ; lb. per plot of 1/20 acre.*)

Plot No.	Treatment.		(1) MANURE.			(2) SOIL.			(3) CROP.			(4) DIFFERENCE.		
			N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O
4.	Control ...	+	0.0	0.0	0.0	20.0	1.5	—	—	—	—	—	—	—
		–	—	—	—	—	—	4.2	20.8	9.3	22.0	0.8	7.8	26.2
5.	NP ...	+	19.8	28.5	0.0	10.0	1.3	—	—	—	—	4.7	18.2	—
		–	—	—	—	—	—	1.2	25.1	11.6	26.6	—	—	27.8
6.	NK ...	+	19.8	0.0	25.7	20.0	4.2	—	—	—	—	4.2	—	—
		–	—	—	—	—	—	3.3	35.6	16.2	35.9	—	12.0	13.5
7.	PK ...	+	0.0	28.5	25.7	0.0	1.3	—	—	—	—	—	15.5	—
		–	—	—	—	—	—	4.4	31.3	14.3	31.7	31.3	—	10.4
8.	NPK ...	+	19.8	28.5	25.7	0.0	—	—	—	—	—	—	9.5	—
		–	—	—	—	—	0.5	5.0	41.5	18.5	42.4	21.7	—	21.7
12.	Lime (L) ...	+	0.0	0.0	0.0	20.0	—	—	—	—	—	—	—	—
		–	—	—	—	—	2.1	0.9	28.3	12.6	28.7	8.3	14.7	29.6
13.	LNP ...	+	19.8	28.5	0.0	20.0	—	—	—	—	—	12.5	8.6	—
		–	—	—	—	—	7.8	1.7	27.3	12.1	28.3	—	—	30.0
14.	LNK ...	+	19.8	0.0	25.7	20.0	—	—	—	—	—	—	—	—
		–	—	—	—	—	1.5	0.0	41.9	18.5	41.9	2.1	20.0	16.2
15.	LPK ...	+	0.0	28.5	25.7	20.0	—	—	—	—	—	—	4.3	—
		–	—	—	—	—	7.4	1.5	37.4	16.8	37.5	17.4	—	13.3
16.	LNPK ...	+	19.8	28.5	25.7	20.0	—	—	—	—	—	—	—	—
		–	—	—	—	—	9.1	3.6	45.0	20.0	45.4	5.2	0.6	23.3
3.	Organic (O)	+	63.5	39.2	99.4	0.0	—	—	—	—	—	2.0	9.8	34.6
		–	—	—	—	—	3.3	3.7	61.5	26.1	61.1	—	—	—
11.	OL ...	+	63.5	39.2	99.4	0.0	—	—	—	—	—	—	2.8	29.9
		–	—	—	—	—	9.2	7.2	64.0	27.2	62.3	0.5	—	—
9.	OLNP ...	+	83.3	67.7	99.4	0.0	—	—	—	—	—	28.3	32.0	35.1
		–	—	—	—	—	12.1	10.0	55.0	23.6	54.3	—	—	—
1.	OLNK ...	+	83.3	39.2	125.1	—	—	—	—	—	—	16.1	4.5	56.1
		–	—	—	—	10.0	9.7	11.6	57.2	25.0	56.9	—	—	—
10.	OLPK ...	+	63.5	67.7	125.1	—	—	—	—	—	—	—	21.6	53.1
		–	—	—	—	10.0	18.6	10.1	63.6	27.5	61.9	10.1	—	—
2.	OLNPK ...	+	83.3	67.7	125.1	—	—	—	—	—	—	4.9	25.3	50.1
		–	—	—	—	10.0	13.0	8.4	68.4	29.4	66.6	—	—	—
			Av. nutrient uptake by all crops					...	44.0	19.3	44.0	—	—	—
			Av. uptake for plots treated with organic manure					...	61.6	26.5	61.2	—	—	—

Note.—Additions denoted by + sign ; first line. Removals denoted by – sign ; second line.

The second column gives the contribution by the soil, based on its chemical analysis at the beginning and end of the experiment (*See* Table II). The third column gives the total amounts of nutrients removed by the crops grown during the whole course of the experiment, assuming that the magnitude of the crop produced by the highest-yielding plot in each series had been an average high value, expressed as 100. No account has been taken of possible fixation of atmospheric nitrogen by nodule bacteria associated with the leguminous crops, nor by free-living nitrogen-assimilating organisms, nor by photo-catalytic processes. The fourth column shows the excess or deficit of supply over removal.

Discussion.

Large discrepancies occur in the balance sheet. Excess (positive signs in Column 4) may be taken as indicating the adequacy of the manurial treatments (except that the values do not allow for losses other than removal by the crop), while deficits (negative signs in Column 4) may be assumed to denote manurial deficiencies.

(*a*) *Nitrogen.*—On the whole, the only treatments that appear to have satisfied the nitrogen requirements of large crops have been those that included organic manure. Organic manure alone, in the absence of sulphate of ammonia, proved just about sufficient for the needs of large crops, while organic manures *plus* sulphate of ammonia more than satisfied requirements, assuming no fixation of nitrogen from the atmosphere. These findings agree with those derived from soil analysis.

(*b*) *Phosphate.*—All the treatments which contained superphosphate have proved adequate in satisfying the phosphate requirements of large crops. Organic manure applied alone has also proved adequate for phosphate, while combinations of organic manure and superphosphate have yielded considerable excesses of phosphate.

(*c*) *Potash.*—The unit dressing of sulphate of potash applied has proved entirely inadequate for supplying the crops' needs, but organic manure has provided a considerable excess of potash.

(V) Comparative Nutrient Status of the Manurial Treatments.

The evidence from soil analysis and nutrient uptake, considered in relation to crop yields, enables an approximate comparison to be made between the nutrient status of the different manurial treatments employed in this experiment.

(1) Organic Manure.

(*a*) *Nutrient Effect.*—The superiority of the organic manure apparently has depended largely on its content of nutrients. The actual pen manure and compost used were not chemically analysed, but it may be assumed that they had the average composition of Trinidadian pen manures and College composts. The analytical data employed in the computations are the means of values for nine typical pen manures and six composts, mostly analysed in the College laboratories by G. Rodrigues. Since pen manure and compost were used in about equal amounts, the mean of the two values for each ingredient is taken, thus :—

	Pen Manure.	Compost.	Mixture (1 : 1)
	Per cent.	Per cent.	(Mean) Per cent.
Total organic matter ...	17.0	17.7	17.35
Total ash components...	8.4	6.3	7.35
Total nitrogen (N) ...	0.47	0.44	0.455
Total phosphate (P_2O_5)	0.28	0.28	0.280
Total potash (K_2O) ...	0.54	0.88	0.710
Carbon-nitrogen ratio...	—	—	(14.0)

The total quantity of organic manure applied during the course of the experiment, divided by the number of applications of manure, was 778 lb. per plot. Each single dressing of organic manure thus supplied :—

Total organic matter	134.98	lb. per plot.
Total nitrogen (N)	3.528	,, ,,
Total phosphate (P_2O_5)	2.178	,, ,,
Total potash (K_2O)	5.524	,, ,,

In terms of the artificial inorganic manures used in this experiment, these quantities are equivalent to :—

Sulphate of ammonia (20 per cent. N) 17.64 per plot.

Superphosphate (18 per cent. P_2O_5) 12.10 lb. per plot.

Sulphate of potash (52 per cent. K_2O) 10.62 lb. per plot.

The actual quantities (unit dressings) of artificial manures used were :—

Sulphate of ammonia (20 per cent. N) 5.50 lb. per plot.

Superphosphate (18 per cent. P_2O_5) 8.80 lb. per plot.

Sulphate of potash (52 per cent. K_2O) 2.75 lb. per plot.

Thus, each unit dressing of organic manure was equivalent to 3.21 times the unit dressing of sulphate of ammonia, 1.375 times the unit dressing of superphosphate, and 3.86 times the unit dressing of sulphate of potash.

Additions of nitrogen, phosphate and potash of such substantial proportions might be sufficient to account for the superiority of the organic manure treatment applied in this experiment, quite apart from any other attributes which organic manures might possess.

(*b*) *Colloid Effect*; *Exchange Capacity*.—One of the beneficial effects of organic manures frequently stressed is their ability to increase the water-retaining capacity and the capacity for fixing (adsorbing) basic nutrient ions of a soil because of their large content of colloidal humus, reckoned to be about seven times as active a colloid as inorganic colloidal clay. In order to assess this effect in the case of the soil comprising the Permanent Manurial Experiment, determinations of exchangeable bases and base saturation capacity were made. The results are given in Table IV.

The data obtained show that an average increase of only 8.5 per cent. in exchangeable base capacity has occurred as the result of continuously adding organic manure. The initial exchange capacity was only 8.6 mg. equiv., per cent., which denotes a sandy type of soil,* deficient in colloidal matter. The effect of organic additions on the degree of colloidality cannot therefore be regarded as very marked nor specially significant, and it is doubtful if the organic manuring has permanently improved the water and nutrient adsorbing relations of the soil, though it may have exerted temporary effects before decomposition and oxidation had greatly reduced the quantity of organic matter added. It is also likely that organic manuring has buffered the soil against rapid moisture fluctuations and against extreme changes in reaction as long as the manure lasted. It may also have improved transiently the soil's physical structure which is important in deciding degree of aeration and conductance for water.

(*c*) *Carbonic Acid Effect*.—During the course of the experiment, little accumulation of organic matter occurred as a result of organic manuring above that which could be attributed to root residues, so that most of the added organic carbon must have been oxidised. The amount of dry organic matter added to each plot by a single dressing of organic manure was 135 lb., with carbon-nitrogen ratio 14, and total nitrogen content 3.528 lb. Thus, nearly 50 lb. of carbon were added at each treatment, which, when oxidised, would yield 183 lb. or 1,646 cubic feet of carbon dioxide per plot. Much of this gas would dissolve in the soil water, and so increase its solvent activity on soil minerals (such as potash-mica and apatite), as well as limestone added to the soil. That such action has at least affected the limestone is indicated by the much greater degree of alkalinity of plots that were merely limed as compared with plots that were both limed and treated with organic manure. In the first case, the reaction was changed from pH 6.0 to pH 8.1, indicating more than 100-fold increase in alkalinity, while in the second case it was changed from pH 6.4 to pH 7.8, an increase in alkalinity only about 14-fold.

* Values around 20 mg. equiv. per cent. are regarded as marking the border-line between sandy and clayey (colloidal) soil-types. Thus, the Chocolate Soil of the Montserrat District of Trinidad shows an exchangeable base capacity of 40 units, and the black and red clay soils of the Naparima District show values between 25 and 55 units.

TABLE IV.—EXCHANGEABLE BASE STATUS OF THE PLOT SOILS.

(*Surface 6-ins layer*)

Plot Treatment. (Lime; Organic Manure)	Silt + Clay %	Reaction. Norm. pH	Reaction. Exch. pH	O.M. Content %	Total N %	Exch. Bases. CaO mg. Eq.	Exch. Bases. MgO %	Satn. Capac. CaO mg. Eq.	Degree of Satn. by Lime %
(A) Neither ...	51.0	6.2	5.6	1.58	0.13	3.9	0.70	8.75	44.5
(B) Lime alone (L) ...	51.0	8.1	7.5	1.52	0.11	8.7	1.60	8.40	103.6†
(C) Organic alone (O)	48.7	7.3	6.8	1.96	0.15	7.3	1.25	9.55	76.5
(D) Lime *plus* organic (OL) ...	45.5	7.8	7.5	2.08	0.15	9.8	1.25	9.06	108.2‡
Mean Values :—									
Increase due to lime	—	—	—	0.03	loss	3.6	—	(loss) (0.42)	45.4
Increase due to Organic Manure	—	—	—	0.47	0.03	2.2	—	0.73	32.0

† Contains 0.21 per cent. free calcium carbonate.
‡ ,, 0.30 ,, ,, ,,
Sample (A) Composite, Plots 4, 5, 6, 7, 8 (Control, NP, NK, PK, NPK).
,, (B) ,, Plots 12, 13, 14, 15, 16 (L, LNP, LNK, LPK, LNPK).
,, (C) ,, Plot 3 (O).
,, (D) ,, Plots 1, 2, 9, 10, 11 (OLNK, OLNPK, OLNP, OLPK, OL).

(*d*) *Other Effects.*—It is not possible on the data available to demonstrate or to assess other possible beneficial effects said to be conferred by organic manuring, for example, (i) protection of the soil surface against water loss by evaporation, (ii) provision of a more suitable medium for mycorrhizal development, (iii) supply of growth-promoting substances, such as "plant hormones" contained in the urine of farm animals, or trace elements concentrated in vegetable residues. While some of these benefits may have been conferred by the application of organic manures in this experiment, their significance is only conjectural and doubtless of minor importance as compared with the direct nutritional effect of the large additions of nitrogen, phosphate and potash.

(2) Potash Manure.

The unit dressing of sulphate of potash used in this experiment was evidently not sufficient to satisfy the requirements of large crops nor to raise the potash status of the soil to an adequate level. The average *deficit* per plot was apparently about 16 lb. K_2O, or 0.9 lb. K_2O per plot per crop, equivalent to 1.75 lb. of sulphate of potash. The actual dressing used was only 2.75 lb. per plot per crop.

The potash contained in the unit dressing of organic manure was more than sufficient to satisfy requirements; it raised the potash status of the soil almost to a suitable level. The average *excess* per plot was around 33 lb. K_2O, or 1.8 lb. per plot per crop, equivalent to 3.5 lb. of sulphate of potash. According to the chemical analysis, the sulphate of potash equivalent of the organic manure dressing was actually 10.62 lb. per plot per crop, whereas 10.62 *minus* 3.5, or 7.1 lb. would have sufficed.

The combination of sulphate of potash and organic manure naturally proved also to be excessively rich in potash, the average excess per plot being 53 lb. K_2O, or 3 lb. per plot per crop, equivalent to 5.8 lb. sulphate of potash. The actual sulphate of potash equivalent of the dressing was 10.62 *plus* 2.75 lb., or 13.37 lb. per plot per crop, whereas 13.37 *minus* 5.8, or 7.6 lb. would have sufficed, a result which agrees closely with the value 7.1 lb. obtained for the organic manure alone.

(3) Phosphatic Manure.

In contrast to potassic manure, the unit dressing of superphosphate used in the Permanent Manurial Experiment seems to have been sufficient to supply the needs of the crops grown on the artificial manure plots, and to have raised the available phosphate status of the soil well above the level of adequacy. Indeed, the dressing was evidently too large by about 4.4 lb., *i.e.* it was twice too much.

Organic manure, applied alone, also provided more than enough phosphate for the needs of the crops it produced. Its actual superphosphate equivalent was 12.1 lb., as against 8.8 lb., which was the unit dressing of superphosphate. The amount of surplus phosphate which it provided was equivalent to about 3.0 lb. of superphosphate per plot per crop, so that the amount utilised was about 9.1 lb. per plot per crop, or just over the amount of the unit dressing of 8.8 lb.

Organic manure *plus* superphosphate seems to have supplied a surplus equivalent to about 8.1 lb. of superphosphate above the requirements. Its superphosphate equivalent actually was 12.1 *plus* 8.8, or 20.9 lb., of which 20.9 *minus* 8.1, or 12.8 lb. was utilised by an average crop receiving the combined dressing, as compared with 9.1 lb. in the case of organic manure alone.

The exact rôle of phosphate in crop production is not fully understood, but it is believed that, unlike the other two nutrients, nitrogen and potash, large excesses of phosphate are readily tolerated by plants. Abundant phosphate may thus be taken up in "luxury consumption" without deleterious effects on plant metabolism. In the presence of free calcium carbonate or active hydrous iron oxide, phosphate may become "fixed" in a relatively insoluble form. Furthermore, it may be absorbed in considerable quantities by soil micro-organisms which possess large phosphate requirements. It is therefore a wise precaution always to provide an excess of phosphate when manuring soils for high crop production. In the case of this experiment, the unit dressing of 8.8 lb. of superphosphate would perhaps be regarded as satisfactory, though it might with advantage be increased, say to 11 lb. per plot per crop, when high crop yields are expected.

(4) Inorganic Nitrogenous Manure.

The unit dressing of sulphate of ammonia employed in this experiment seems to have been sufficient when either phosphate or potash was omitted but not sufficient when they were also supplied. This result occurred both where lime had been added and where it had been withheld. The data are somewhat erratic, but on the average the unit dressing of sulphate of ammonia (5.5 lb.) would appear to be about one-half too small, *i.e.* the deficit of nitrogen on the artificially manured plots was about 1 lb. per plot per crop, equivalent to 5 lb. of sulphate of ammonia.

Organic manure, applied alone, just satisfied the needs of the crops it supported. Its actual ammonium sulphate equivalent, assuming all its nitrogen was available, was 17.64 lb. as against 5.5 lb., the unit dressing of sulphate of ammonia.

Organic manure *plus* sulphate of ammonia supplied a surplus of nitrogen equivalent to about 6.5 lb. of sulphate of ammonia. Its actual equivalent was 17.64 *plus* 5.5, or 23.14 lb., of which 23.14 *minus* 6.5, or 16.64 lb. was utilised by the large crops produced, as against 17.64 lb. in the case of organic manure alone.

It is evident that the unit dressing of sulphate of ammonia was much too small. The evidence from the data for the organic manured plots suggests that it might with advantage be raised from 5.5 lb. per plot per crop to about 17 lb., *i.e.* increased at least three-fold.

The ammonium sulphate equivalent of the 5 cwt. unit dressing of organic manure would be 12.7 lb., whereas that of the original unit dressing (778 lb., or nearly 7 cwt.) was 17.64 lb. Thus, if the smaller unit be accepted for future use, on the basis of its potash equivalence with the new unit dressing of sulphate of potash, a deficiency of nitrogen would be imposed. On the other hand, if the larger unit dressing of organic manure be used, it would supply sufficient nitrogen, but at the same time, it would supply excessive amounts of potash. This would be wasteful, and it is therefore recommended that equivalence with regard to potash be favoured in designing the new unit dressings.

(5) Lime.

It has already been noted that the yield data (Table I) failed to reveal any appreciable increase in production that might be attributed to liming; any benefits that lime may have conferred must therefore have been offset by certain deleterious effects. It is evident at once that the dressing applied was far in excess of the actual lime requirement of this type of soil. Calculation from the data for exchangeable calcium and exchange capacity (Table IV) proves that the theoretical lime requirement was about 2.25 tons of calcium carbonate per acre 6-ins. of soil, or say four tons of ground limestone, containing 50 per cent. of the 100-mesh fraction, whereas the actual dressing given was ten tons per acre, equivalent to one per cent. of the weight of the soil. Such an excessive amount might be expected to exert harmful effects at first, and indeed the data indicate this, for the yields for 1932-33 averaged 92 units for limed plots receiving no organic manure as against 100 for unlimed plots, whereas for 1936-37 they averaged 126 units. In other words, the liming depressed the yields at first, but later the limed soil produced more than the unlimed. Similar results were obtained for plots that had been treated with organic manure; here, the average yield for 1932-33 was 90 units, and for 1936-37, it was 111 for limed soil, as against 100 for unlimed soil. Evidently the initial deleterious effects diminished with the progress of time.

Among the chief undesirable properties of soils containing an excess of calcium carbonate (even though that excess be localised and only temporary) is the immobilisation of phosphate, so that plants cannot utilise it. Investigators in Arizona* have indicated that the fixed phosphate in calcareous soils occurs as insoluble calcium phosphato-carbonate and alumino-phosphate which are formed at reactions between pH 8.0 and pH 8.5. Furthermore, plant roots seem to be less able (at least in water culture) to absorb phosphate-ion when the reaction of the medium is more alkaline than pH 7.6 than when it is near to, or more acidic than, neutrality. At high alkalinity, iron and manganese, as well as other "trace elements" such as boron, now known to be essential to complete plant nutrition, are also unavailable, occurring in the soil only as insoluble compounds. Chlorosis may develop as a result of iron and manganese deficiency in crops growing in calcareous soil.

When recently-limed soils are exposed to continuous leaching by natural carbonated water, calcium carbonate is mobilised and distributed uniformly throughout the soil, while some may be lost in the drainage water. This equalising process reduces the effects of localised alkalinity, and gradually eliminates them altogether. Treatment with ammonium sulphate or with organic manure expedites calcium carbonate removal, the one by generating nitric acid and the other, carbonic acid, through oxidation.

In the Permanent Manurial Experiment, actual measurement showed that the amount of free calcium carbonate in the limed plots was reduced from one per cent. (ten tons per acre, surface six inches of soil) to less than 0.3 per cent., though the degree of saturation by exchangeable lime was still practically 100 per cent. at the end of the six years' period (Table IV). The final reaction of the limed soil was pH 8.1 for the surface 6-ins. layer, and pH 7.4 for the second 6-ins. layer, indicating downward leaching. Thus the phosphate status of the soil, *inter alia*, doubtless improved as the experiment progressed, and this may have mainly accounted for the increasing yielding capacity of the limed plots in recent years (Table I). The liming eventually increased the reserve of available phosphate in the soil at the end of the period, but the laboratory soil data may be unreliable since it is known that the Truog method, here applied for estimating available phosphate, does not yield accurate results with calcareous soils.*

(VI) Nutrient Ratios of Original and Recommended New Manurial Dressings.

According to the above findings, the most suitable unit dressings for high crop production on the soil of the College Farm would be:—

Sulphate of ammonia, 17.0 lb., or 3.40 lb. nitrogen per plot.

Superphosphate of lime, 11.0 lb., or 1.98 lb. phosphate per plot.

Sulphate of potash, 7.5 lb., or 3.90 lb. potash per plot.

* *See* Technical Bulletins, Nos. 35, 36, 40, 41, 57; *Agric. Expt. Sta., Univ. Arizona*, published between 1931 and 1935; by W. T. McGeorge and J. F. Breazeale on the peculiar phosphate relations of alkaline calcareous soils.

* *See* "The Phosphate Requirement of Calcareous Soil", by F. Hardy, D. M. Hanschell and E. H. Amoroso-Centeno, *Trop. Agric.*, XV, 1938, pp. 183-86.

The ratio between the main ingredients for a complete manure obtained by mixing these unit dressings is :—$1\frac{3}{4}:1:2$. For the organic manure, the ratio is $1\frac{1}{4}:\frac{3}{4}:2$, showing unbalance with respect to the ratio of nitrogen to potash. The ratio of nutrients contained in the plant material* produced by the manured soil in this experiment (bottom of Table III) is :—$2:\frac{3}{4}:2$, showing nearly identical nitrogen : potash ratio with that of the "ideal" manure, with a slightly superior potash status for the manure, as would be expected in view of the marked potash requirement of the soil that has to be manured.

The nutrient ratio between nitrogen and phosphate and between potash and phosphate is about 2 : 1 in the "ideal" manure. Whether this is entirely satisfactory is not certain ; it may err in the direction of too much phosphate for the needs of field crops, but this would not be regarded as objectionable since it is desirable always to maintain a high phosphate status of a soil in order to counteract the effects of fixation and leaching. An excess of phosphate is not considered to be harmful when absorbed in "luxury consumption" by crop-plants.

* It is interesting to note that the ratio of nitrogen to potash suitable for high production of vegetables and flowers by "soil-less" culture methods has been found to be the same as this, namely, 1 : 1. Thus, satisfactory results were obtained by soil-less culture methods with an artificial manure whose nutrient ratio was $N : P_2O_5 : K_2O$: : 15 : 3 : 15. The manure was applied dry to the sand bed forming the growth medium.

See "Soil-less Culture Simplified", by Alex. Laurie, McGraw-Hill, New York 1940. (*Nature*, 1940, p. 633.)

(VII) Summary and Recommendations.

(1) The soil of the Permanent Manurial Experiment has been proved to be deficient in available potash, total nitrogen and available phosphate. Measured crop yields, chemical soil analysis and the construction of a rough "balance sheet" of nutrients have contributed to an approximate assessment of these deficiencies, the aim being to devise an artificial manure mixture suitable for high production of short-period field crops, such as maize, cotton, tobacco, millets, hill-rice, and various leguminous cover crops.

(2) The unit dressings of *artificial manures* initially selected for application in this experiment have proved to be both insufficient in quantity and unbalanced as regard nutrient ratio for the

TABLE V.—UNIT MANURIAL DRESSINGS ; ORIGINAL AND REVISED.

Simple Manure.	1 Artificial Manure.	2 Organic Manure (778 lb.)	— Main Ingredients.	3 Artificial Manure.	4 Organic Manure (778 lb.)	5 Nutrient Ratios. Artific. Manure.	6 Nutrient Ratios. Organic Manure.
	Lb. per plot per crop (3 crops per year).						
(A) UNIT DRESSINGS ORIGINALLY APPLIED.							
Sulph. Amm. ...	5.50	17.64	Total N	1.10	3.53	2	2
Superphosphate ...	8.80	12.10	,, P_2O_5	1.58	2.18	3	$1\frac{1}{4}$
Sulph. Potash ...	2.75	10.62	,, K_2O	1.43	5.52	$2\frac{1}{2}$	3
(B) RECOMMENDED NEW UNIT DRESSINGS† (Revised on basis of *Potash Equivalence*).							
	Lb. per plot per crop (3 crops per year)						
		(560 lb.)			(560 lb.)		
Sulph. Amm. ...	17.0	12.46	Total N	3.40	2.49	$1\frac{3}{4}$	$1\frac{1}{4}$
Superphosphate ...	11.0	8.71	,, P_2O_5	1.98	1.57	1	$\frac{3}{4}$
Sulph. Potash ...	7.5	7.65	,, K_2O	3.90	3.98	2	2
(C) ALTERNATIVE NEW UNIT DRESSINGS (Revised on basis of *Nitrogen Equivalence*).							
	Lb. per plot per crop (3 crops per year).						
		(784 lb.)			(784 lb.)		
Sulph. Amm. ...	17.0	17.64	Total N	3.40	3.53	2	2
Superphosphate ...	11.0	12.10	,, P_2O_5	1.98	2.18	$1\frac{1}{4}$	$1\frac{1}{4}$
Sulph. Potash ...	7.5+2.5	10.62	,, K_2O	5.20	5.52	3	3

† *Recommended new unit dressings for general application* to College Farm Soil, in terms of quantities per acre per year :—

(1) Sulphate of Ammonia ; 680 lb. ac., or 6 cwt. ac.
(2) Superphosphate of lime ; 440 lb. ac., or 4 cwt. ac.
(3) Sulphate of potash ; 300 lb. ac., or 3 cwt. ac. (approx.).
(4) Organic manure ; 10 tons ac., mixed pen manure and rich compost, or 15 tons ac. average pen manure.

Note.—This mixture is sufficient for two major field crops per year, without irrigation.

requirements of these crops. The original dressing of sulphate of potash was a little more than one-third of the actual requirement, that of superphosphate was about adequate, while that of sulphate of ammonia was less than one-third the requirement.

(3) The unit dressing of *organic manure* proved not to be chemically equivalent to the unit dressing of mixed artificial manures. It supplied nearly four times as much potash, nearly one-and-a-half times as much phosphate, and more than three times as much nitrogen. It was also unbalanced in nutrient ratio.

(4) It is accordingly recommended that the unit dressing of organic manure be reduced to 5 cwt. per plot (5 tons per acre), and that the unit dressings of artificial manures be increased and adjusted on a basis of *potash equivalence* with the organic manure. The initial amounts and the recommended new amounts of the unit dressings of artificial manures are set out in Table V, Sections (A) and (B).

(5) Alternatively, if it be desired to adjust the unit dressings on a basis of *nitrogen equivalence*, the organic manure dressing should be maintained at 7 cwt. per plot (7 tons per acre). In this case, however, the unit dressing of artificial potash manure might prove inadequate, but an increase in its amount sufficient to restore potash equivalence would cause unbalance in the ratio of nitrogen to potash (Table V, Section (C)).

(6) The greater crop yields given by the application of organic manure in this experiment may satisfactorily be explained by its superior nutrient status. No evidence could be adduced to demonstrate significant effects that might be attributed to any other property of organic manure.

(7) The dressing of ground limestone applied in this experiment was apparently nearly three times too large; evidence is offered to suggest that, at first, the excessive dosage exercised deleterious effects, probably by lowering the phosphate status of the soil, but that, in due course, these effects disappeared and beneficial effects superseded. It is recommended that no more lime be applied for many years to come, since the calcium status of the soil is at present satisfactory.

PHYSIOLOGICAL BASIS OF PLANT NUTRIENT DEFICIENCY SYMPTOMS.

A large and apparently increasing number of chemical elements is coming to be recognised as necessary, or in some cases beneficial if not essential, to the normal growth and reproduction of higher plants. The quantitative requirements of the respective elements vary from minute traces to comparatively large amounts, and the concentrations tolerated by plants are limited to a very narrow range with some elements, but extend over wide ranges with others. The toleration of a wide range of concentrations of the major nutrient elements is an important factor enabling plants to adapt themselves to varied soil environments.

In spite of this adaptability, symptomatic indications of maladjustments in crop plants have become increasingly prevalent in recent years. Biochemical studies of normal and affected plants, considered in connection with growth and yield response to soil treatment, have contributed to an understanding of the relation between plant symptoms and the disturbances in plant metabolism brought about by malnutrition. The results lead to more accurate diagnosis of plant malnutrition by aid of symptoms.

Some findings reported in this paper are as follows :—

(1) The most frequently observed cases of malnutrition are those of deficiencies of one or more essential elements, which may be interpreted as excesses of the elements not deficient.

(2) Deficiencies are relative ; a sufficient supply of an element under one condition becomes insufficient as other elements become more abundant.

(3) Deficiency may be due to (*a*) insufficient supply in soil ; (*b*) insufficient solubility rate ; (*c*) physiological unavailability as in failure of "acid sensitive" plants to absorb Ca at low pH ; and (*d*) physiological unavailability within the plant, as failure to reduce absorbed nitrate, preparatory to protein synthesis.

(4) There are many kinds of symptoms, roughly grouped into : (*a*) inhibited growth, no specific symptoms ; (*b*) colour symptoms usually in leaves ; (*c*) necrosis of tissues, usually in leaves ; and (*d*) malformation of different parts of plants.

(5) Plant nutrient deficiencies produce symptoms indirectly, the symptoms resulting from a series of physiological processes usually out of balance with respect to their respective rates.

(6) Being an indirect result, a given symptom may follow more than one original cause, *e.g.* purple-leaved young corn plants may result from phosphorus starvation, from nitrogen starvation, from a series of cold nights with warm sunny days, or from transverse creasing of the leaves ; although the immediate cause of the symptom in the leaf is the same in each case.

(7) The manner of expression of a deficiency by symptoms is subject to modification by environmental conditions, as temperature, humidity, &c. ; and, as a result, the same deficiency in a given crop may produce different symptoms in different geographical regions.

Because of the complicated relations existing between plant maladjustments and plant symptoms, the latter may be considered only as diagnostic aids, rather than as diagnostic methods of certainty. As knowledge of the relation between symptoms and fundamental plant processes increases their diagnostic value also increases.—(E. E. de Turk in *Chemistry and Industry*, Vol. LIX, No. 41, 1940, pp. 698-9.)

NEW DEVELOPMENTS IN SYNTHETIC CHEMICALS AND MATERIALS IN THE RUBBER INDUSTRY.*

THE fact that rubber has become one of our most valuable and widely used structural materials can be attributed primarily to two of its molecular characteristics. First, Nature's rubber is made up of extremely long, chain-like molecules in which the atoms are so arranged that a product with a high degree of elasticity is obtained. Second, the pronounced chemical unsaturation of the rubber molecule makes it possible to link the individual chains together by chemical reaction—curing or vulcanization—with sulphur to produce a firm structure of appreciable strength.

According to our present concept, natural rubber is a polymer of isoprene. The problem of developing synthetic rubber-like materials has, therefore, generally been approached by attempting to reproduce the long-chain, unsaturated, molecular structure through polymerization of isoprene or of other, more readily available, simple, conjugated dienes, such as butadiene and chloroprene. More recently, similar results have been obtained by chain polymerization of simple olefines with only limited amounts of diolefines.

Some of the synthetic diene rubbers tend to have less than the theoretical amount of unsaturation, which indicates that some of the double bonds have been consumed in the development of cross-linkages or bridges between chains. Such cross-linking makes for a three-dimensional polymer rather than a two-dimensional chain structure, and is probably responsible for the somewhat resinous properties that are in evidence in these products.

Early efforts of chemists working in this field, were directed toward synthesizing a product that would duplicate natural rubber. This work led to the development of such products as methyl rubber and Buna. The more recent trend is to synthesize materials closely resembling Nature's product in some respects, while at the same time surpassing it in others. This is clearly illustrated by such products as neoprene, Buna-S, and Perbunan, each of which exceeds natural rubber in certain specific properties.

Although a great many different synthetic diene rubbers have been announced, it would seem that so far we are dealing with only a limited number of distinct types. If ability to vulcanize with sulphur is taken as a criterion for a true rubber-like material, the known products may be classified as representing four basic types from the standpoint of the nature of the polymer chain and characteristic physical and chemical properties.

Some of the more recently announced products, on which less extensive technical information is available, may be assumed to belong to the third class. Thiokol is probably the only product usually classified as a synthetic rubber that does not fit into this classification. As a condensation product of chlorine-containing organic compounds and sodium polysulphide, it does not—like the diene polymers—undergo curing with sulphur.

As far as conditions in the U.S.A. are concerned, the immediate aim of the synthetic rubber industry has been to compete with Nature's product on a quality rather than a price basis. Natural rubber has in the past sold as low as three cents per pound and as high as $1.35 per pound. In 1940, market quotations have fluctuated round 20 cents per pound. Estimates of the cost of producing and delivering plantation rubber vary somewhat, but seven to eight cents per pound may be taken as a fairly representative figure. Considering that Perbunan was sold at 95 cents per pound when the importation ceased as a result of the War, and that neoprene is selling at 65 cents per pound, it is obvious that these products are being consumed where advantage can be taken of those properties in which they are definitely superior to natural rubber.

The various "synthetic rubbers" have already been tested extensively in uses for which they have not yet found general application because of price considerations. Thus, although more difficult to process by conventional factory methods, some of these products can be built into tyres which are equal, and in some respects even superior, to those made from natural rubber. Buna-S has been found to give wear equivalent to that of the best rubber tyre treads. Under the best conditions of both compounding and service, Perbunan has proved 10 to 20 per cent. better. Neoprene gives results equal to Buna-S.

Starting Material.	*Product.*
1. Di-olefine	...Natural rubber (isoprene) Buna (butadiene) Methyl rubber (dimethyl-butadiene) Russian products - SKA, SKB (butadiene)
2. Chloroprene (possible also with modifiers)	Neoprene Sovprene
3. Di-olefines + modifiers	Buna-S (butadiene + styrene) Perbunan or Buna-N (butadiene +acrylo-nitrile)
4. Olefines + di-olefines	Butyl rubber.

* (Abridged from an article in *News Edition, American Chemical Society*, Vol. 18, No. 22, 1940, pp. 979-980.)

THE EFFECT OF GRASS LEYS IN IMPROVING SOIL STRUCTURE.

In discussing the physical factors affecting soil conservation, Dr. Richard Bradfield* has lucidly described the probable method of formation of stable granules induced by the rootlets of grasses. He writes :—

" Practically all soils as far as I know are found to be in better physical condition after they have grown a heavy crop of grass or preferably a grass-legume mixture for a few years. For generations farmers have realized that for some reason cultivated crops grew better following such a mixture. Under grass most soils assume a granular or crumb structure. The exact mechanism of the formation of these crumbs is not fully understood, but the result obtained is universally regarded by soil physicists as the ideal physical state for the growth of most crops. It is best developed in soils which are saturated with lime and which contain from 3 to 10 per cent. organic matter. Having these amounts of lime and organic matter in the soil however, will not ensure a good granular structure. Something else is needed. The organic matter must be of the proper type and it must be properly distributed. I have tried to picture to myself how these granules might be formed and why they are so important. Additional evidence is needed, but I feel that the picture is reasonably accurate.

" Grass roots are so numerous that in a well-established sod they are seldom over 3 to 5 millimeters apart. These roots ramify the soil in all directions. Each root represents a center of water removal. As water is removed from the soil in contact with the root, additional water moves toward the root by capillarity. As water is removed the small fragment of soil between the roots shrinks and is blocked off by the roots. The pressure developed by the capillary forces, compressing the granule from all sides, is great, in many soils it reaches over 5,000 pounds per square inch. As a result, these granules become quite dense, their specific gravity ranging from 1.8 to 2.0. The total pore space inside them is small and the size of the pores is very small. Water moves into them slowly but is held firmly. The pores are so narrow that they are easily completely sealed by capillary water and as a result the ventilation of the interior is poor. Consequently, reducing conditions frequently exist on the interior of the granules simultaneously with oxidizing conditions on their surface. This often causes a migration of substances which are more soluble when in the reduced form to the surface of the granule where they are oxidized and deposited. This deposit serves as a cement and helps to stabilize the granule. Very hard granules of soil may be formed by the compression due to surface tension alone, but such granules are not water stable. When immersed in water, the air-water interface gradually disappears throughout and the granule breaks to pieces.

"In forcing its way through the soil many cells are sloughed off the living root and serve as food for bacteria. Eventually, the roots die and are decomposed *in situ*, forming a humified, often water-resistant coating around the granule. The marked difference in colour between the surface of such granules and their interior is evidence of this. In many respects it seems to me these tiny granules may be compared to miniature 'earths'. Most of the inhabitants live near the surface where the 'air' is better. In the strongly granulated soil practically the entire mass of clay and silt particles are clumped together in these water-stable aggregates. As a result there are two fairly sharply defined groups of pores in such soils, capillary pores within the granule and non-capillary pores between the granules. The non-capillary pores are relatively large. Water enters them readily but is retained only at the periphery. This leaves a continuous series of connecting chambers through which air can readily pass. The water at the periphery is drawn into the capillary pores between the unit particles making up the granules. This water constitutes the most closely held reserve in the soil. Such a soil has a permeability approaching that of sandy soils combined with a storage capacity of the heavier textured soils."

* Soil Conservation from the viewpoint of Soil Physics, by Richard Bradfield; *Journal of the American Society of Agronomy*, Vol. XXIX, No. 2, Febuary, 1937.

RESUSCITATION OF STORM DAMAGED BANANA FIELDS.

Banana trees which have been blown down or badly battered should be chopped into 18-inch lengths, split into half with the inner surface turned up and this surface chopped in a criss-cross manner. The trunks so treated are used to form a useful mulch and, more important, the treatment prevents the alarming increase in banana borer infestation which usually follows heavy wind damage. The uprooted tree should be dug out and if there is a follower this should be dug out too and replanted. Followers not so treated take longer to fruit and tend to grow out of the ground with lowered resistance to wind. If one of two healthy large trees in a matt is uprooted the butt must be excavated and the hole filled in with soil. If the destruction is such as to leave the ground bare and unshaded, cover crops of leguminous plants should be sown, one suggested being Overlook beans. These beans should be cut down when flowering and left as mulch. The stumps will then shoot again and give a good crop.—(*Imp. Bur. of Hort. & Plant. Crops, Hort. Abstracts*, Vol. X, No. 2, Abs. 715, p. 172, 1940.)

CHEMICAL NOTES.

(Compiled by the College Department of Chemistry and Soil Science.)

Radioactive Tracer Elements in the Study of Plant Growth*.—*By A. Keith Brewer.*

During the past few years, a method has been developed for tracing the course of a specific group of atoms through complicated biological processes. This is made possible by the use of isotopes which are indistinguishable by an organism from ordinary atoms; yet they are readily detected by present-day instruments.

Isotopes may be classified either as natural or artificial; these may be sub-divided as stable and radioactive. In tracer research, the natural-stable and artificial-radioactive types are of primary interest, both being necessary in a complete study of the element. Isotope utilization involves production and detection. Natural isotopes are separated from ordinary matter by either chemical or physical means and are detected by the mass spectrograph. Artificial radio-isotopes are produced by bombardment from some high energy source and are detected by a Geiger counter. The technique of isotope analysis is rapidly becoming simplified, so that in a few years it should be within the scope of the most modest laboratory, and it will doubtless accelerate or replace many present-day methods.

While a preponderance of isotope research has been applied to animal organisms, many new and confirmatory results have been obtained with plants. The greatest advance has been made in studying the rate of mineral assimilation under varying conditions, the distribution of elements within the plant, and the factors controlling elimination. Isotope studies of stability of molecules *in vivo* and *in vitro* have also thrown much new light on the functioning of vital processes.—(*Chemistry and Industry*, Vol. LIX, No. 41, 1940, pp. 697-698.)

* *Bureau of Plant Industry, U.S. Department of Agriculture, Washington, D.C.*

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Early Manuring Needs of Sugar-Cane.*—*H. Evans.*

Cores were removed from the middle internodes of cane cuttings by means of a cork borer; the holes were filled with a mixture of equal parts of urea and di-potassium phosphate (K_2HPO_4); the holes were sealed with cork stoppers and the seed pieces were grown in moist sawdust for three months. In comparison with control pieces, the treated pieces produced more shoots and showed much better growth of shoots and roots. Also, when the plants were analysed the leaves and stems from the treated pieces were found to contain more nitrogen, phosphate and potash than those from the untreated pieces. When a similar experiment was made under field conditions, the internally treated cuttings gave better results than did either the controls or other cuttings that were planted with the same quantity of the fertilizer mixture placed in the ground near the seed piece. On the other hand, ammonium salts had a marked toxic effect when placed inside the seed piece.—(*Facts About Sugar*, 1940, Vol. XXXV, No. 10, October, p. 33.)

* *Annual Report, Mauritius Department of Agriculture*, Vol. 8, pp. 58-59.

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Sequencies in the Application of Fertiliser to Sugar Cane.—*By Fernando Chardon.*

(Paper read before the Association of Sugar Technologists of Puerto Rico.)

Some Puerto Rican cane planters consider that when successive applications (two or more) are made, each application should consist of a complete fertilizer. Others prefer to apply ammonium sulphate first and follow it with a complete fertilizer. But the practice which appears to be most in vogue is to make a first application of complete fertilizer, and four or eight weeks later, to follow it up with an application of ammonium sulphate. In some cases where the amount of fertilizer used is very large, there are two or more applications of complete fertilizer, but there is always a final application of ammonium sulphate. To find out which, if any, of these practices is superior to the rest, a four-year experiment was made with four treatments of the same experimental fields.

The four treatments were as follows:—

Treatment.	1st Application.			2nd Application.		
	NH_3	P_2O_5	K_2O	NH_3	P_2O_5	K_2O
1	150	50	120	—	—	—
2	75	25	60	75	25	60
3	75	50	120	75	—	—
4	75	—	—	75	50	120

The second application was made eight weeks after the first. In all cases the total amount of fertilizer used in the two applications was the same. The average yields of the four crops were as follows:—

Year.	Treatment.	Yield, tons.
1935	1	36.55
1936	2	36.19
1937	3	36.92
1938	4	35.12

The statistical analysis of the results does not show any significant superiority of one treatment over another.—(*The International Sugar Journal*, Vol. XLII, No. 500, p.293, 1940).